HILGARDIA

A Journal of Agricultural Science Published by the California Agricultural Experiment Station

VOL. 17 JANUARY, 1947 NO. 6

DEPOSITIONAL AND WEATHER-RESISTING QUALITIES OF SOME COPPER FUNGICIDES AFFECTING THE CONTROL OF PEACH BLIGHT[1]

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INTRODUCTION

IN THE TESTS reported in this paper, comparisons were made between the depositional and weather-resisting qualities of bordeaux and three so-called fixed copper fungicides used to control peach blight caused by the fungus *Coryneum beijerinckii* Oud. Each fixed copper preparation was combined with a supplement to increase the tenacity, or weather resistance, of the deposit.

STUDIES ON DEPOSITION

On Peach Twigs.—In field tests conducted for three seasons, water suspensions of basic copper sulfate A,[3] basic copper sulfate Z (containing zinc), cuprous oxide, and bordeaux mixture were applied in mid-November to peach trees after most of the leaves had fallen. One-half per cent of a cream-type oil emulsion, designated as supplement A,[4] was added to basic copper sulfate A. One and one-half per cent of an emulsive oil, supplement B, was added to basic copper sulfate Z and to cuprous oxide. The emulsifying agents and other ingredients of these supplements are unknown to the writer. Except in the first year of the tests, each preparation was applied to three randomized plots with an ordinary orchard sprayer operated at a pressure of 450 to 500 pounds per square inch.

In addition to these treatments, basic copper sulfate Z, suspended in an emulsive oil which was then emulsified in water (1 gallon of oil to 1 gallon of water), was applied by means of vapor-spraying equipment. This machine produces a finely divided mist by injecting the preparation into an air stream, which issues from ducts at the side of the machine.

After the sprays had dried, samples of twigs produced in the previous growing season were collected; the copper deposits were determined by the iodo-

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[3] The basic copper sulfate designated as A (Basi-Cop) contained 52 per cent metallic copper; that designated as Z (Zinc-Coposil) contained 19 per cent copper; the cuprous oxide (yellow coprocide) contained 84–85 per cent copper.

[4] The trade name of supplement A is Basi-Spred; of supplement B, Ortho-Adhesive.

metric method as described in another paper (Wilson, 1942). In late February, other samples were taken and the residues remaining after weathering were determined. Table 1 gives these data, the results of four trials conducted in three different years.

Average initial deposits shown in the second column of table 1 differed considerably among the various preparations. This finding might be expected, since the copper content of the prepared sprays also differed. For example,

TABLE 1

COMPARISON OF COPPER FUNGICIDES WITH INITIAL DEPOSITS, RESISTANCE TO WEATHERING, AND CONTROL OF PEACH-TWIG INFECTION BY *Coryneum beijerinckii*, 1941–1944

Fungicide material, pounds per 100 gallons, and supplement used, expressed in per cent by volume	Milligrams of copper on 100 grams of twigs		Average coefficient of tenacity†	Average number of lesions on 100 twigs
	Average initial deposit	Average residue*		
Unsprayed	....	....	.....	1,770
Bordeaux, 10–10–100	32.8	8.0	0.239	62
Bordeaux, 10–10–100; plus supplement B, 1 per cent	29.6	9.6	0.348	16
Bordeaux, 8–8–100; plus supplement B, 1 per cent	26.3	10.4	.....	.....
Basic copper sulfate A, 5–100; plus supplement A, 0.5 per cent	47.2	9.8	0.207	99
Basic copper sulfate Z, 6–100; plus supplement B, 1.5 per cent	19.6	4.5	0.222	78
Basic copper sulfate Z, 8–100, plus supplement B, 1.5 per cent	26.9	4.3	.....	.....
Cuprous oxide, 1.5–100; plus supplement B, 1.5 per cent	24.7	5.6	0.239	186
Vapor application, basic copper sulfate Z, 75–100, in 50 gallons of an emulsive oil and 50 gallons of water, applied at the rate of 20 gallons per acre	19.4‡	6.7‡	0.345‡	28
Difference required for significance 19:1 odds	9.6	3.6	0.135	.....
Difference required for significance 99:1 odds	13.5	5.1	0.189	.....
Calculated F value	10.2	5.1	1.61	.....

* After weathering for approximately 3.5 months; average rainfall, 8.59 inches.

† Tenacity coefficient = ratio $\frac{\text{residual spray deposit}}{\text{initial spray deposit}}$. These values, being the averages of the individual coefficients of tenacity, are not necessarily the same as those obtained by dividing the average residue by the average initial deposit.

‡ Excluded from analysis of variance.

preparations of basic copper sulfate Z, 6 pounds per 100 gallons of water, and cuprous oxide, 1½ pounds per 100 gallons, contain 0.137 and 0.152 per cent copper, respectively, as against 0.299 per cent for bordeaux of 10–10–100 strength. These preparations deposited, respectively, 19.6 and 24.7 milligrams of copper on each 100 grams of twigs, as against 32.8 milligrams to each 100 grams for bordeaux. When the initial deposits were compared with respect to the copper content of the spray preparation, however, all fixed copper materials proved to be deposited in greater relative amounts than bordeaux. The coefficients of deposit reported in figure 1 were computed as follows: The amount of copper deposit, y, of the material in question proportional to the deposit, b, of bordeaux (10–10–100) was obtained by $y = \frac{bx}{0.299}$, where x is the copper content (in per cent) of the preparation of the material in question

and 0.299 is the per cent of copper in the bordeaux preparation. The observed deposit divided by the expected deposit gave the coefficient. The coefficient for bordeaux, 10–10–100, of course, would always be 1.0.

Bordeaux preparations with and without supplement B were deposited at the same relative level; but all fixed copper materials were deposited in amounts 29 to 49 per cent higher than bordeaux, 10–10–100, without supplement. A difference of 32 per cent is required for significance at 19 : 1 odds.

Since the amount of preparation applied per tree with the vapor equipment varied somewhat between tests and since each test of this treatment consisted of one plot only, the results given in table 1 were excluded from the statistical

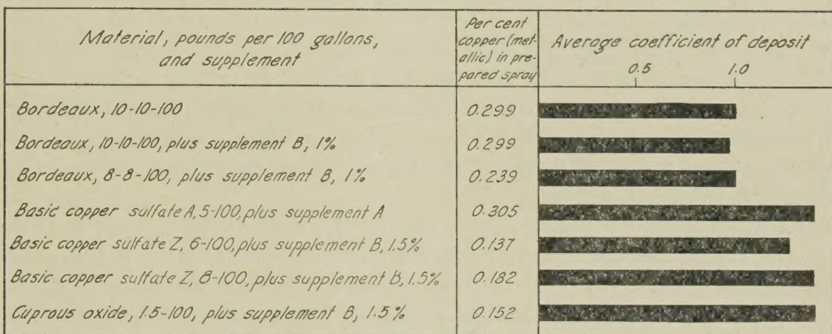

Fig. 1.—Deposition of copper fungicides on peach twigs relative to equivalent copper contents of the prepared sprays.

analyses. In these trials the vapor preparation gave deposits about equal to that of basic copper sulfate Z, 6–100, applied with the regular sprayer, and only 41 per cent lower than that of bordeaux, 10–10–100. On the other hand, deposits of basic copper sulfate Z applied by vapor equipment in a commercial almond orchard were 58 per cent lower than deposits of bordeaux, 10–10–100. Large variations in deposits by this method of application might arise from difference in the speed with which the sprayer is drawn past the trees. As will be shown later, the amount of spray retained by a solid surface up to the time the liquid begins to drain away is directly proportional to the length of the application period. Since the rate of liquid delivery from the vapor equipment is low, under ordinary circumstances the amount deposited on twig surfaces is seldom great enough to cause runoff. Thus, marked variations in the application period should result in differences in the amount of spray deposited on the surfaces; and since the vapor spray issues from more or less fixed outlets, the speed of the sprayer will determine the amount of deposit.

With the ordinary spray rig, on the other hand, the amount of liquid required to cover a given number of trees was approximately equal for all materials. Why, therefore, did the fixed copper materials consistently deposit relatively greater amounts of copper than did bordeaux? For a study of this point, the sprays had to be applied under conditions less variable than those in the orchard. A laboratory atomizing applicator, described earlier (Wilson, 1942), was employed. The surface to be sprayed was a thin film of cellulose nitrate deposited on glass slides.

On Artificial Surfaces.—To understand the method by which supplements might affect the spray deposits, one must consider how the liquid behaves during application. Hensill and Hoskins (1935) emphasized the dynamic nature of deposition. In the first place, the sprayed surfaces are seldom horizontal, so that gravity greatly affects the retention of liquid by the surface. Second, the forces that influence wetting and spreading properties are not permitted to attain equilibrium during application, because the deposited droplets are constantly being disturbed by the oncoming spray. Methods for determining the wetting and spreading under static conditions give results that are of little value for assessing the effects of these properties on retention of spray deposits. In general, however, if the surface is partially wetted by the preparation, an increase in the wetting properties will result in a decrease in deposit (Evans and Martin, 1935; Fajan and Martin, 1937; Hoskins and Ben-Amotz, 1938). Surfaces not wetted by a liquid will retain none of the deposit, because the droplets roll off. Under such conditions, an increase in the wetting properties increases the deposit (Hensill and Hoskins, 1935). Maximum retention of solutions and ordinary suspensions by a surface, therefore, occurs at some intermediate stage of wetting.

For solutions and ordinary suspensions, the maximum deposit is present when the liquid begins to run from the surface (Evans and Martin, 1935; Fajan and Martin, 1937). Continuing to spray beyond this stage ordinarily results in a decrease in the amount retained. Under certain conditions, however, an increase in deposit of a suspended solid occurs when application is continued beyond the stage at which the liquid runs off. Fajan and Martin (1938), for example, reported preferential retention of cuprous oxide by artificial surfaces when the preparation contained petroleum oil emulsified by Agral II. Such was not the case, however, with oil containing sulfite lye as an emulsifier. Under the microscope the oil droplets were seen to aggregate about the cuprous oxide particles when Agral II, but not when sulfite lye, was the emulsifier. Such observations indicate that a partial wetting of the cuprous oxide by the oil occurred with the Agral but not with the sulfite lye. A still more striking case of increased deposits resulting from application beyond the runoff stage is reported for the "dynamite" spray by Marshall (1937) and Marshall and Groves (1937). This spray is prepared by adding a petroleum oil containing one of the univalent soaps, such as ammonium or triethanolamine oleate, to a water suspension of lead arsenate. According to Marshall (1937), the lead arsenate becomes wetted by the oil before, or at the time the liquid comes in contact with the sprayed surface. Very high deposits of lead arsenate are obtained with this preparation.

Although the supplements used in the field trials herein reported contain oil, information on the nature of the emulsifying agents or other added materials was not available to the writer. When these supplements were added to water suspensions of the fixed copper fungicides, a distinct flocculation occurred. Under the microscope the flocculated phase was seen to consist of fungicide particles and water droplets surrounded by oil. Thus the system is apparently much like that of the "dynamite" spray described by Marshall (1937).

Aside from a slight curding, bordeaux was not affected by either supple-

ments A or B, nor by a supplement prepared with oil and ammonium oleate. According to field tests, moreover, bordeaux deposition was not affected by supplement B. To show how supplements affect the deposition of the fixed copper fungicides and of bordeaux, the laboratory applicator was employed. Although the earlier work of this nature has been largely concerned with the amount of deposit at certain stages of spray application, such as "runoff"[5] (Evans and Martin, 1935; Fajan and Martin, 1937 and 1938), or after a definite amount of liquid had drained from the surface (Hensill and Hoskins, 1935; Hoskins and Ben-Amotz, 1938), more detailed data were desired in the

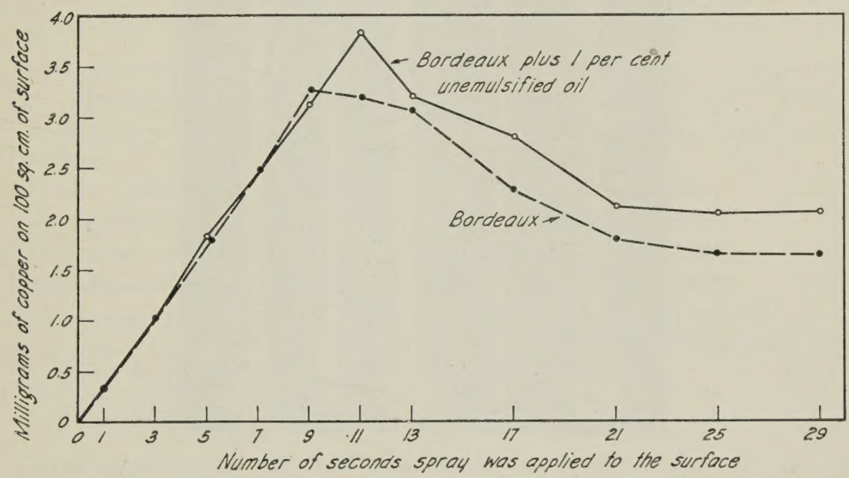

Fig. 2.—Deposition of 1 per cent bordeaux (by weight), and the same bordeaux plus 1 per cent of unemulsified petroleum oil, on cellulose nitrate surfaces.

present tests. In an attempt to determine the building up of the copper deposit before runoff and the status of that deposit after liquid had drained from the surface, glass slides coated with cellulose nitrate in series of five were sprayed for increasing lengths of time, and the amount of copper was ascertained for each spraying interval. In this way the amount of copper deposited by each fungicidal preparation could be compared at the same stage of application relative to runoff.

The atomizer type of applicator has one main limitation: it will not deliver coarsely flocculated preparations at a constant rate, because the floccules tend to accumulate in the atomizer. Since this difficulty was encountered particularly with basic copper sulfate A combined with supplement A and with cuprous oxide combined with supplement B, bordeaux and basic copper sulfate Z with and without supplement B were used in the more detailed tests.

The first point to be examined is the deposition of bordeaux, which will illustrate what happened when an ordinary suspension or, for that matter, a solution was applied for increasing lengths of time. Figure 2 shows the results of tests in which series of slides were sprayed with 1 per cent bordeaux

[5] "Runoff" is used for convenience in designating the stage when the liquid deposit begins to run from the surface, but before any is lost.

with and without unemulsified oil for 1, 3, 5, 7, 9, 11, 13, 17, 21, 25, and 29 seconds. Preliminary trials determined the length of time spraying must continue before runoff begins, and the time intervals were spaced so that one series of slides was sprayed just to the runoff stage. These slides, therefore, bore the maximum deposit.

Before runoff started, deposition of bordeaux or bordeaux with an unemulsified oil was proportional to the length of time the spray was applied. The addition of 1 per cent unemulsified petroleum oil increased the length of time

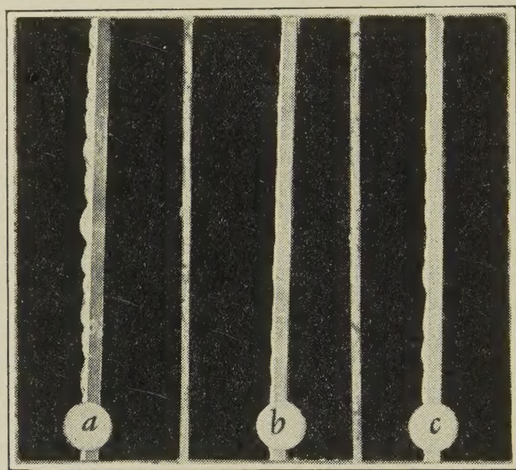

Fig. 3.—Edge view of glass slides showing the liquid deposits of various sprays at the stage just before the liquid began to run off: *a*, 1 per cent copper sulfate solution; *b*, 1 per cent bordeaux mixture; *c*, 1 per cent bordeaux mixture plus 1 per cent of an unemulsified petroleum oil. The spraying time necessary to start these sprays running down the surface was 13.4, 5.5, and 6.8 seconds, respectively.

spraying was necessary to cause running of the liquid from the surface. Thus, when spraying was ended at the runoff stage, the deposit of copper was increased by the addition of unemulsified oil. This increased deposit had one or both of two causes: the oil decreased the wetting properties of the preparation, or the oil increased the viscosity of the preparation. The thickness of the liquid deposits of copper sulfate, bordeaux, and bordeaux plus an unemulsified oil sprayed to the runoff stage is illustrated by the photographs in figure 3. Here the liquid deposit of bordeaux is seen to be much thinner than that of bordeaux containing oil or that of copper sulfate. Apparently, therefore, bordeaux spray droplets spread over larger areas than those of the other preparations, probably because they wetted the surface to a greater degree.

Preparations of fixed copper fungicides without supplements wetted cellulose nitrate surfaces less than bordeaux. In consequence, when application ended at the runoff stage, these materials were deposited in greater amounts than bordeaux. On the whole, the supplements increased the amounts of these fungicides present when the runoff began. Although, for reasons given earlier,

the results with cuprous oxide plus supplement B and basic sulfate A plus supplement A were not always reliable, the data given in figure 4 are believed to represent the situation fairly well.

In practice, spraying is seldom discontinued at the runoff stage. Dripping of spray from the surface occurs particularly on twigs at the periphery of the trees. From the artificial surface (fig. 2), bordeaux lost as much as 40 per cent of the deposit present at runoff when spraying was continued beyond that stage. It seemed desirable, therefore, to determine the behavior of the copper deposit during the time the spray was running from the surface. For this purpose, bordeaux and basic copper sulfate Z with and without supplements were applied to cellulose nitrate surfaces for 0, 4, 8, 12, 16, and 20 seconds after

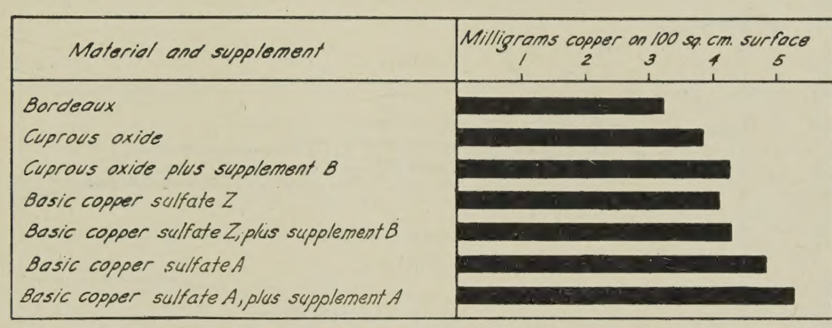

Fig. 4.—Deposition of bordeaux and of various other copper fungicides (with and without supplements) on cellulose nitrate surfaces sprayed to the runoff stage.

the liquid began to run off. The three supplements used were: first, the proprietary material designated B in the field tests; second, a petroleum oil (70 per cent U.R., 108 seconds Saybolt viscosity) containing 0.5 per cent ammonium oleate; third, the same petroleum oil emulsified with 6 milligrams of blood albumin per 100 cubic centimeters of oil. Both supplement B and the supplement containing ammonium oleate flocculated the fixed copper fungicide but did not affect bordeaux in this respect, whereas petroleum oil containing blood albumin did not flocculate either material.

According to the results in figure 5, all supplements tended to lower somewhat the amount of bordeaux deposit retained by the surface at the time runoff began (0 seconds). As will be remembered, supplement B in the field tests (table 1) did not affect the deposit of bordeaux on peach twigs to a significant extent, though there appeared to be a very slight decrease. Either with or without supplements, the bordeaux deposit on cellulose nitrate decreased when spraying was continued beyond the runoff stage. In contrast, when no supplement or when oil containing blood albumin was added to the fixed copper, the deposit decreased when spraying was continued after runoff began; but when either supplement B or oil containing ammonium oleate was added, the curve was strikingly different. Deposits (curves *b* and *c* for basic copper sulfate Z) are seen to decrease as the liquid begins to run from the surface (4 to 8 seconds after runoff begins); but as application continues, they increase. Such behavior presumably results from the preferential retention of the copper phase. The liquid that runs off, consequently, contained less solid than

when it struck the surface. Apparently, therefore, only certain types of emulsifying agents promote this phenomenon. Judging from the results with supplement A in the basic sulfate A and supplement B in cuprous oxide, preferential retention occurred here also; but detailed trials similar to those reported in figure 5 were not attempted, since the floccules of these materials clogged the atomizer, and thus reduced the accuracy of the results.

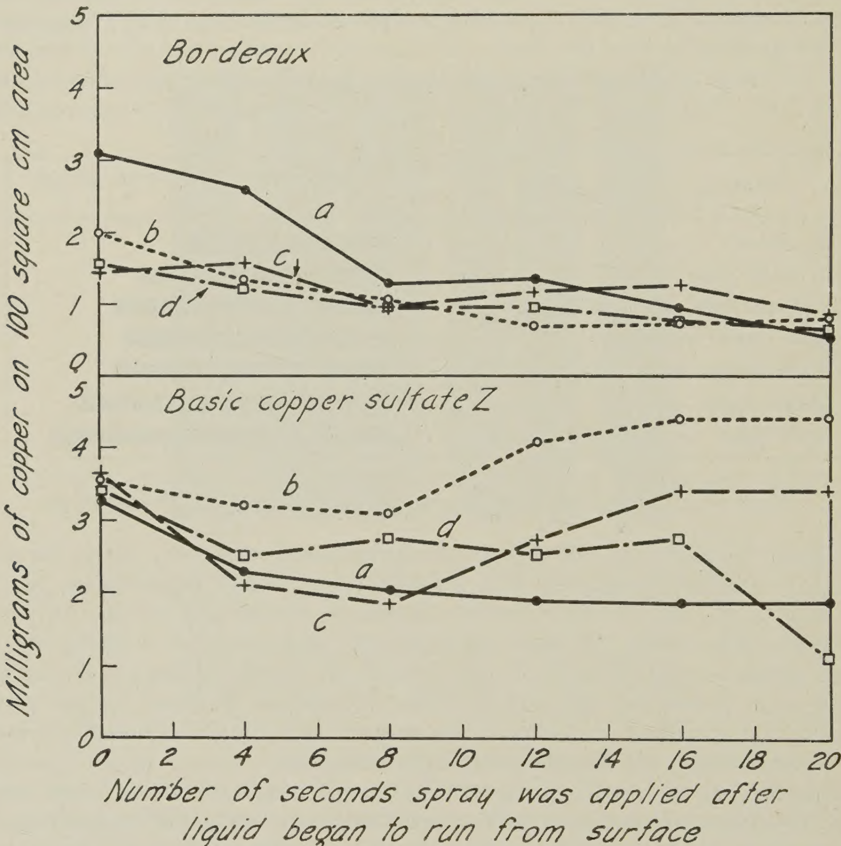

Fig. 5.—Effect of oil-containing supplements on the deposition of bordeaux and basic copper sulfate Z on cellulose nitrate surfaces: *a*, no supplement; *b*, 1.5 per cent supplement B; *c*, 1.5 per cent petroleum oil emulsified by ammonium oleate; *d*, 1.5 per cent petroleum oil emulsified by blood albumin.

WEATHER RESISTANCE

The standard program for preventing the peach-twig infection caused by *Coryneum beijerinckii* consists of a single spray applied in the fall after the leaves are off the trees. To remain effective against the disease, therefore, the fungicide must resist washing away by rains over a long period (as much as 100 days in some seasons).

Table 1, fourth column, shows the weather resistance (tenacity) of bordeaux with and without a supplement, and of the fixed copper fungicides with their

respective supplements. The data for the vapor application were excluded from the analysis of variance because this material was applied to one plot only. On the whole, deposits by the vapor preparation resisted weatherings better than any of the other deposits. There was one exception: bordeaux with supplement B proved significantly more tenacious than basic copper sulfate A plus supplement A, or basic sulfate Z plus supplement B, and exhibited a strong tendency to resist weathering better than bordeaux without a supplement, or cuprous oxide plus supplement B.

CONTROL OF TWIG INFECTION

Twig infection, severe in 1942 and 1943, became too sparse for test purposes in 1944. According to the results in the fifth column of table 1, all materials

TABLE 2

EFFECTIVENESS OF COPPER FUNGICIDES IN CONTROLLING PEACH-TWIG INFECTION CAUSED BY *Coryneum beijerinckii*, 1945

Fungicide material, pounds per 100 gallons, and supplement used, expressed in per cent by volume	Average number of lesions on 100 twigs
Unsprayed	388
Bordeaux, 10–10–100	45
Bordeaux, 8–8–100; plus supplement B, 1 per cent	26
Basic copper sulfate A, 5–100; plus supplement A, 0.5 per cent	47
Basic copper sulfate Z, 6–100; plus supplement B, 1.5 per cent	43
Cuprous oxide, 1.5–100; plus supplement B, 1.5 per cent	67

reduced the disease greatly. Some differences in effectiveness, however, were apparent. For example, cuprous oxide appeared somewhat less effective than the other materials. On the whole, bordeaux (without supplement) gave better control than the fixed copper materials that were applied with the regular spray equipment. On the other hand, the vapor application of basic copper sulfate Z was, if anything, superior to bordeaux without supplement. Bordeaux containing supplement B (one year's tests), however, apparently surpassed all other materials.

Table 2 gives additional data secured in 1945, when the disease was moderately severe. Again, bordeaux with supplement B proved most effective and cuprous oxide least effective, whereas the control by bordeaux without supplement, by basic copper sulfate A, and by basic copper sulfate Z were of the same order of effectiveness.

Table 1 shows a lack of correlation between the amount of copper residue remaining on the twigs throughout the winter and the prevention of twig infection. For example, the average residues of bordeaux, 10–10–100, plus supplement B and basic copper sulfate A differed but little; yet the bordeaux treatment was the more effective. Although the amount of copper was less on trees sprayed with basic copper sulfate Z than on trees sprayed with bordeaux 10–10–100, control of twig infection differed little between the two. Basic copper sulfate Z, as will be recalled, contains 19 per cent zinc, which possibly helped to prevent the disease.

SUMMARY AND CONCLUSIONS

Studies herein reported concerned orchard and laboratory comparisons of bordeaux and three fixed copper fungicides (plus proprietary adhesive) with respect to their depositional, weather-resisting, and disease-preventive qualities.

In proportion to the amount of copper in the spray preparations, the fixed copper materials deposited 29 to 49 per cent more copper than bordeaux did. On the other hand, various preparations of bordeaux, some with and some without an oil-type supplement, differed but little in this respect.

Laboratory tests were designed to study the deposition of the various preparations on an artificial surface. The materials were applied to glass slides (coated with cellulose nitrate) by means of a precision applicator for the same length of time, and the amount of copper retained by the surface was determined. The liquid deposit of bordeaux was retained by the surface in direct proportion to the length of the application period up to the time the liquid began to run from the vertically held surface. If application was continued beyond runoff, however, the deposit decreased for a time, but then reached a stage where it remained approximately constant. Sometimes the loss of copper through runoff was 40 per cent of the deposit present just before runoff began.

Addition of an unemulsified petroleum oil to bordeaux increased the amount of liquid deposit and, consequently, the amount of copper deposit retained by the surface at the runoff stage. The increased deposit was evidenced by the longer period of application necessary to cause the liquid to run from the surface, and was probably due to one or both of two factors: a decrease in the wetting properties of the spray preparation, or an increase in the viscosity of that preparation.

Water suspensions of the fixed copper fungicides wetted cellulose nitrate less readily than did bordeaux. For this reason the amount of liquid retained by vertical surfaces at the runoff stage was higher than when bordeaux was used. When application was continued beyond runoff, the liquid deposit of the suspensions decreased much as did that of bordeaux. When, however, certain proprietary supplements or a supplement containing a petroleum oil emulsified with ammonium oleate was added to these suspensions, copper was retained by the surface in increasing amounts as application continued beyond the runoff stage. This situation was attributed to the preferential retention of the oil, and the copper suspended therein, by the sprayed surface. According to microscopic evidence, the flocculated phase of these preparations consisted of oil globules enclosing fungicide particles and droplets of water. When petroleum oil emulsified with blood albumin was added to suspensions of fixed copper fungicides, no flocculation occurred; that is, the copper particles were not wetted by the oil. Preferential retention of these particles by the sprayed surface, moreover, did not occur with such preparations.

Under the experimental conditions, the solid phase of bordeaux was not wetted by the supplements; neither was there evidence of preferential retention.

Loss of deposit by weathering was determined in the orchard. In three seasons when rainfall averaged 8.59 inches, the coefficients of tenacity were

as follows: bordeaux, 0.239; bordeaux with supplement B, 0.348; basic copper sulfate A (vapor application), 0.345; cuprous oxide, 0.239; basic copper sulfate Z (applied with regular spray rig), 0.222; basic copper sulfate A, 0.207. All fixed copper preparations were combined with an oil-type supplement.

Though all preparations greatly reduced twig infection by *Coryneum beijerinckii,* bordeaux with supplement B and the vapor application of basic copper sulfate Z appeared somewhat more effective than basic copper sulfate A, basic copper sulfate Z, and cuprous oxide.

The amount of copper residue remaining on the tree throughout the infection period (the winter months) was not always correlated with the degree of twig-infection control. This finding suggests that some residues may have been more toxic to fungus spores than others; but the data are insufficient for conclusions.

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SNAPDRAGON DOWNY MILDEW

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SNAPDRAGON DOWNY MILDEW[1]

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SNAPDRAGON downy mildew, caused by *Peronospora antirrhini* Schroet., has been recorded only on *Antirrhinum orontium*, a wild species of Europe, and on *Antirrhinum majus*, the cultivated snapdragon. Kenneth F. Baker[3] found this mildew on *Antirrhinum nuttallianum* at Otay Lake, San Diego County, California, in 1941. All varieties of snapdragon inoculated by the writer, or observed under conditions of heavy natural infection, have been susceptible. Murphy (*13*)[4] indicates that dark-colored varieties are the most susceptible. In a heavy natural infection at Guadalupe, California, in 1940, breeding lines with dark, waxy foliage had fewer infected plants than light-colored ones.

Peronospora antirrhini was first reported on *Antirrhinum orontium* in 1874 (*15*) from Germany, on this same species in Switzerland in 1907 (*10*), and in Denmark in 1913 (*12*). It is not recorded to have caused commercial damage until 1936, when Murphy (*13*) in Ireland reported it to be severe on nursery seedlings of cultivated snapdragons. It has since been found in England (*1, 7, 8*), New South Wales (*2*), California (*9*), Pennsylvania (*11*), and Oklahoma (*14*). McWhorter[5] found the disease at Portland, Oregon, in the spring of 1944. Snapdragon mildew was first observed by the writer on May 25, 1938, on specimens brought in by a nurseryman near Hayward. By 1940 it not only was severe throughout the San Francisco Bay district, but also had appeared in southern California.

IMPORTANCE OF THE DISEASE

Snapdragon downy mildew has been principally a seedling disease of nursery plants. Systemically infected plants are unsalable. They are unsuitable for planting because they generally fail to grow and finally die. Losses have varied from none to all plants in a given planting. The standard practice in the San Francisco Bay area is to plant about 1,000 snapdragon seeds per flat, and later to transplant the resulting seedlings at the rate of 100 to 120 seedlings per flat. The plants are sold in the second flats within a few days to a few weeks after transplanting. If more than about 10 plants per flat show systemic infection, the entire flat is usually discarded. One nursery in Oakland discarded its entire stock of 600 flats of snapdragons at one time because of downy mildew infection. In 1940–1942 the infection was so generally destructive in southern California that it was impossible to obtain healthy seedlings. At a seed farm at Guadalupe, 90 to 95 per cent of the plants in 1,400 flats were lost because of mildew in January, 1940, and at a nursery in Los Angeles about 1,000 flats were discarded because of mildew in 1942. Murphy (*13*) and Green (*7, 8*) also indicate extensive nursery losses in Ireland and England.

Losses may also occur on greenhouse plants grown for cut flowers, but the writer has little information on how severe this may be.

[1] Received for publication January 12, 1946.

[2] Assistant Professor of Plant Pathology and Assistant Plant Pathologist in the Experiment Station.

[3] All observations in southern California are those of Kenneth F. Baker, Associate Professor of Plant Pathology, and Associate Plant Pathologist in the Experiment Station.

[4] Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

[5] F. P. McWhorter of Oregon State College, in a personal communication to the author dated December 10, 1945.

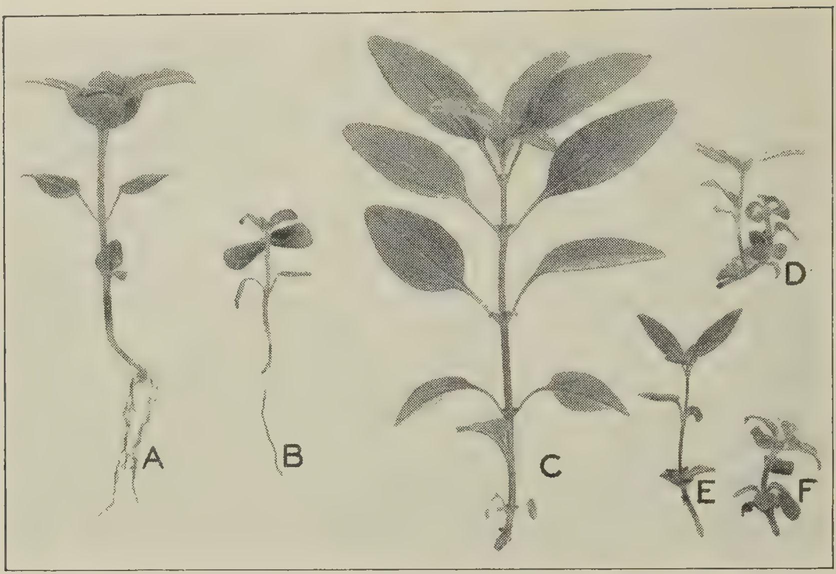

Fig. 1.—Symptoms of systematic infection of downy mildew on seedling snapdragons. *A*, healthy noninoculated plant; *B*, inoculated. *A* and *B* were the same age and size at time of inoculation on February 21, 1940; photographed March 7, fourteen days after inoculation. *C*, healthy noninoculated plant; *D, E, F*, inoculated; *C, D, E, F* were the same age and size at time of inoculation on February 1, 1940; *C, D, E, F*, photographed March 26, fifty-three days after inoculation; *D* shows recovery by growth of a lateral noninfected shoot; *E* shows recovery by growth of a terminal healthy shoot; and *F* shows no recovery.

Fig. 2.—Symptoms of systemic infection of downy mildew on snapdragons grown in the greenhouse for cut flowers; plant and individual leaves on right are healthy; plant and individual leaves on left show systemic infection. Systemically infected plants are shorter than normal; leaves show basal infection. Photographed January 29, 1942.

SYMPTOMS

The most important infections of downy mildew on snapdragons are systemic and the symptoms are characteristic of systemic infections of other downy mildew diseases. On seedling plants there is a downward curling of the leaves, a reduction in the size of the leaves and of the plants, and the infected leaves are paler green than normal. On seedlings, downy mildew causes a stunting or killing which progresses from the top of the plant down to the soil surface; it is thus readily distinguished from the common damping-off of seedlings which kills the plants from the taproot in the soil up to the soil surface. Symptoms may appear from the time when the plant has two cotyledons and continue to appear until the plants are about 6 inches tall (fig. 1). They may appear again on the growing points of plants, 1 to 4 feet tall, which are coming into flower (fig. 2). On these large plants, there is a rosetting of the growing points. It is not suggested that plants between these specified stages of growth are immune, but infection has not been observed on them by the writer. Furthermore, in the writer's inoculation tests, systemic infection has not occurred on plants inoculated when they are more than about 4 inches tall. Unfavorable environmental factors may well have contributed to these failures. Local (nonsystemic) infections of leaves are common but are rarely destructive. They consist of pale rounded areas up to 15 millimeters in diameter with smooth diffuse margins.

The disease is rare in garden or field plantings, but on May 24, C. M. Tompkins found the disease severe on seedling plants grown outdoors at Colma under conditions of overhead sprinkling irrigation but in a growing season without rain for several previous weeks.

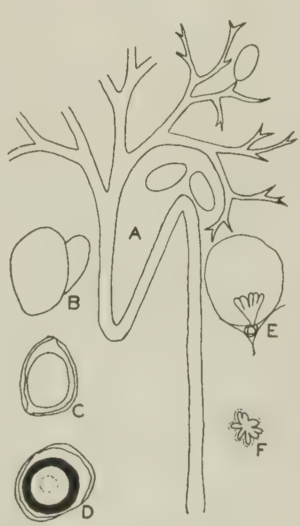

Fig. 3.—*Peronospora antirrhini: A*, portion of sporangiophore, showing attached and detached sporangia (the sporangiophore is illustrater as bent in order to reduce the size of the illustration); *B*, early stage in oöspore formation with antheridium on side of oögonium; *C*, later stage, oöspore formed; *D*, mature oöspore enclosed in oögonium; *E*, branched intracellular haustorium in host cell and intercellular hypha; and *F*, surface view of haustorium indicating protoplasmic sheath.

ETIOLOGY

Snapdragon downy mildew is caused by *Peronospora antirrhini* Schroet.—a typical downy mildew. Sporangiophores and sporangia (conidiophores and conidia) are borne principally on the lower leaf surface, but also in abundance on the stems and upper surface of the leaves of young succulent plants. Sporangiophores emerge through the stomatal openings, are 350 to 704μ long, dichotomously branched, with 27 to 140 ultimate branches, each bearing an ovoid sporangium. Sporangia are 14–17 by 21–29μ and have been observed to germinate by a germ tube only. The internal intercellular mycelium bears intracellular haustoria with 4 to 8 fingerlike branches, similar to those of

Pseudoperonospora on cucumber and hop, and not seen previously on any member of the genus *Peronospora* observed by the writer. Oöspores 30 to 33μ in diameter in oögonia 43–52μ in diameter are produced in great abundance in the cortex and pith of systemically infected seedlings. Green (*8*) indicates that in England oöspores were very rare in living plants, but in the writer's material they have been more numerous than in any other downy mildew examined.

The morphologic features of *Peronospora antirrhini* are indicated in figure 3. Quantitative differences in the writer's description and illustrations from the descriptions and illustrations of other observers (*3, 6, 8, 14*) are not considered of any taxonomic significance. The branched haustoria are considered the most useful character in distinguishing this from most other species of *Peronospora*.

The shortest period in which symptoms have appeared in controlled tests has been 4 days after inoculation.

EPIDEMIOLOGY

Snapdragon downy mildew, like most other downy mildews, appears to be favored by low temperatures and high humidity. In one test, leaves from systemically infected plants placed in moist chambers and incubated at a range of temperatures failed to sporulate at 7° C and below, sporulated luxuriantly at 13° and moderately at 19° but not at 22° or above. In one test of the effect of temperature on spore germination, sporangia in drops of water on slides in petri dish moist chambers germinated as follows: at 1°, 0; 4°, 0; 7°, 11 per cent; 10°, 65 per cent; 13°, 37 per cent; 16°, 26 per cent; 19°, 0; and at 22°, 0. No tests of the effect of temperature on infection under controlled conditions have been performed, but greenhouse inoculations of plants during the winter and early spring months have been successful while inoculations during the hotter summer months have been distinctly less so. On the basis of the limited information available, the writer believes the optimum temperature for snapdragon downy mildew is about 10° C.

In the San Francisco Bay region, snapdragon seedlings are grown principally from February to May in unheated greenhouses as bedding plants for sale, and it is under these conditions that downy mildew has been so destructive. A maximum-minimum thermometer placed in one such greenhouse from February 24 to April 2, 1940, and reset every day showed a minimum temperature ranging from 40° to 50° F (4° to 10° C) and averaged 44° F (7° C); while the maximum temperature ranged from 61° to 95° F (16° to 35° C) and averaged 74° F (23° C). The luxuriant development and active spread of downy mildew in greenhouse culture, more active according to the writer's observation than in outdoor culture, indicates that rain plays little necessary part in the epidemiology of this disease.

In southern California, on the other hand, snapdragon seedlings are grown principally under lath or cloth, or outdoors, and the disease is severe under these conditions. Epidemics there are associated with dark, foggy, humid, and rainy weather.

Environmental conditions during the incubation period (from inoculation until the pathogen establishes nutritive relations with the host) are un-

doubtedly most critical in determining the amount of infection. Dry seedling plants in pots were dusted with dry sporangia and placed in a variety of environments for 24 hours and then returned to a heated greenhouse where the amount of systemic infection was recorded 15 days after inoculation. No water was applied to the leaves in any case. The percentages of systemic infection in four trials with inoculations in varying environments, made January 21–28, 1942, with an average of 9 plants per treatment in each trial were as follows:

	Per cent
Moist chamber in heated greenhouse, about 20°C	54
Open bench in heated greenhouse, about 20°C	7
Moist chamber in unheated greenhouse, 7°–15°C	100
Open bench in unheated greenhouse, 7°–15°C	52
Open bench in unheated greenhouse, and with electric fan directed on plants to reduce humidity, 7°–15°C	0

Environmental conditions following the incubation period are probably less important than those during incubation. Plants which had been inoculated and held in a moist chamber overnight were placed in the following contrasting environments: a heated greenhouse with the temperature about 20° C, natural outdoor environment, an unheated greenhouse, and a lathhouse. In two tests, with an average of 12 plants in each environment in each test, the average percentages of systemic infection in the environments listed were 47, 24, 74, and 40 respectively—least, therefore, in the plants left out of doors.

The writer believes that considerable infection in commercial greenhouses is traceable to the contamination of healthy plants in the process of transplanting. Workers contaminate their hands with sporangia by handling infected plants which may or may not show distinct symptoms, and unknowingly transfer these sporangia to healthy plants. On two occasions heavy infection appeared in flats about a week after transplanting.

CONTROL BY SANITATION AND VENTILATION

As snapdragon downy mildew does not yet occur in most regions, its control in these regions by exclusion would appear in order. The most likely method by which the disease could move long distances would appear to be by oöspores in the seed. The sequence of occurrence in Ireland in 1936 (*13*), England in 1937 (*1*), California in 1938 (*9*), New South Wales in 1941 (*2*), Oregon in 1944, Pennsylvania in 1945 (*11*), and Oklahoma in 1945 (*14*) would seem to depend on some such mode of primary distribution. Since oöspores from seedling infections would seem to have little chance of getting into the seed, whereas oöspores in terminal infections of flowering plants could easily contaminate the seed, it would appear that this latter type of infection may be more common than recorded. In a disease-free district it would seem to be a wise precaution not to use seed from diseased areas, if this is possible. Within regions where the disease already occurs, local exclusion, such as avoiding carrying infectious material from an infested to a noninfested nursery, would appear worth while.

Oöspores in infected seedlings which die and disintegrate can readily contaminate the soil in which they are grown, and it would appear logical to

expect that this contaminated soil might be an important source of primary infection. Attempts to eradicate the disease by destroying infected plants are reported by Murphy (*13*), Green (*8*), and Harris (*9*). Those by the latter two were apparently unsuccessful. Two nurserymen have told the writer of their attempts to control the disease by disposing of all snapdragon plants, but the disease reappeared next year. On the other hand, at one seed farm at Guadalupe the sterilization of the soil used for snapdragon seedlings was associated with reduced downy mildew infection for two years. Some nurseries have escaped the disease without any specific precautionary measures.

Where the disease occurs in greenhouses, control by manipulation of environment would seem a definite possibility. Practices which reduce the humidity at the plant surfaces should reduce infection. During the course of greenhouse studies of the disease for two seasons, the writer's plants grown in a heated greenhouse never became infected naturally, though infected plants were frequently close to them. When such plants were heavily dusted with spores, however, 3 out of 16 plants became infected in one test but none became infected in three other tests. Exposing inoculated plants to an air current from an electric fan entirely prevented infection of plants in an unheated greenhouse, though similar plants not exposed to the fan showed 52 per cent infection. This method of control by air movement would appear practical.

CONTROL WITH FUNGICIDES

The success with paradichlorobenzene for the control of tobacco downy mildew (*5*) suggested its use for snapdragon downy mildew. To treat with paradichlorobenzene, frames $23 \times 14 \times 3$ inches (the same size as the flats to be treated) and covered with two layers of cheesecloth on the upper side, were placed over the test flats of plants, and the desired amount of medium paradichlorobenzene crystals was scattered over the surface of the cheesecloth. The entire flats and frames were then covered tightly with oilcloth to confine the fumes overnight, and the oilcloth and frame removed in the morning. Dosages ranged from 0.5 to 2.5 grams paradichlorobenzene per flat and this treatment was repeated every second or third night. Treatments were applied at 5 to 6 p.m. and the treated flats were uncovered about 8 a.m. next morning. In all instances flats of heavily infected plants were placed among the test flats to insure an adequate amount of inoculum but the plants were not artificially inoculated. The results of four tests at two nurseries, presented in table 1, indicate effective control, but with crop injury at dosages of 2 grams or more per flat. Even in the absence of localized necrotic injury this treatment stunted the plants somewhat and on warm nights severe injury sometimes resulted. It is likely that nightly applications with the lower dosages would have been more successful but this type of treatment was not considered practical by either nurserymen or the writer.

Hydrogen sulfide diluted with air or vapors from dilute lime-sulfur was relatively ineffective in eradicating snapdragon downy mildew (*16*), and these vapor mixtures could be used to kill rust infections without killing the downy mildew in the same plants (*17*).

Spray and dust treatments appear more adaptable to nursery practice than vapor treatments, and a variety of sprays and dusts were tried. In some tests

healthy plants were treated with the test fungicides and artificially inoculated within 24 hours. Rosin lime-sulfur (*19*) and cuprous oxide cottonseed oil were tested more thoroughly than other sprays. Rosin lime-sulfur was prepared by adding the required amount of rosin soap and then the required amount of concentrated lime-sulfur to the required amount of water. For example, to prepare 100 cc of 0.5 per cent rosin lime-sulfur, 99 cc of water was first added to a container, then 0.5 cc of rosin soap, and then 0.5 cc lime-sulfur and the whole agitated. Rosin soap was prepared by heating together 14 parts by weight of water, 5 parts of rosin, and 1 part of potassium hydroxide. Results of four trials with a series of dosages of rosin lime-sulfur and cuprous oxide cottonseed oil were analyzed by dosage response methods (*4*).

TABLE 1
CONTROL OF SNAPDRAGON DOWNY MILDEW IN COMMERCIAL NURSERIES WITH PARADICHLOROBENZENE CRYSTALS

Grams of paradichlorobenzene at each treatment	Number of plants counted	Per cent of plants showing systemic infection	Plant injury from paradichloro-benzene
0.0	1,355	53.0	None
0.5	73	22.0	None
1.0	376	22.0	None
1.5	374	18.0	Trace
2.0	444	0.7	Moderate
2.5	176	1.5	Severe

The dosage for 95 per cent control was about 0.3 per cent rosin soap plus 0.3 per cent lime-sulfur for the first mixture and 0.17 per cent cuprous oxide plus 0.17 per cent self-emulsifying cottonseed oil for the second mixture. The curve slopes (mortality probits per log. dose) as determined for data showing between 50 and 100 per cent control was 2.9 for the rosin lime-sulfur and 3.5 for the cuprous oxide mixture. The same and higher concentrations of lime-sulfur and cuprous oxide without the rosin soap or cottonseed oil supplements were less effective. Other spray mixtures tried, and the corresponding percentages of infection resulting, were as follows: 1 per cent bordeaux, 25 per cent; 0.2 per cent bordeaux plus 0.05 per cent glyceryl alkyl resin, 0; 1 per cent burgundy, 0; 0.1 per cent copper sulfate plus 1 per cent rosin soap, 0; 2 per cent of a proprietary copper ammonium carbonate solution containing 2 per cent copper, 25; and 0.03 per cent ferric dimethyl dithiocarbonate (Fermate) plus 0.05 per cent glyceryl alkyl resin, 0.

If effective, dusts are more acceptable to growers than sprays. In tests of methods of evaluating sulfur dust for the control of five downy mildew diseases, sulfur was more consistently effective against snapdragon mildew than against the downy mildews of hop, cucumber, onion, or lettuce (*18*). In six trials in which snapdragon infection in the controls averaged 86 per cent, sulfur dust entirely prevented infection in three trials, but 22, 65, and 100 per cent infection occurred on sulfured plants in three other trials. The cause of these discrepancies is not known, but it may be related to the washing off of the sulfur in the normal practice of watering. Experiment has clearly shown that sulfur dust applied to snapdragons can be so effectively removed by wash-

ing the plants with a water spray that the sulfured washed plants can be readily infected with downy mildew or rust. Other dusts tested and the percentage of infection associated with their use were: pure cuprous oxide, 0; copper lime dust, 30 per cent; a dust consisting of 10 per cent cuprous oxide plus 10 per cent iron oxide plus 80 per cent filler, 40 per cent; and a dust consisting of 50 per cent sulfur plus 5 per cent basic copper sulfate plus 10 per cent iron oxide plus 35 per cent filler, 43 per cent.

The spray (rosin lime-sulfur) and dust (sulfur) which appeared most promising at the time were compared in a test in which different groups of

TABLE 2

Control of Snapdragon Downy Mildew in Commercial Nurseries with Sprays and Dusts

Treatment	Per cent infection		
	Applications every 8 days, Nov. 21 to Jan. 24	Applications every 3 days, April 9 to 25	Applications every 3 days, April 12 to May 3
Control	80	80	59
0.2 per cent cuprous oxide plus 0.2 per cent emulsified cottonseed oil	..	29	3
0.2 per cent bordeaux plus 0.05 per cent glyceryl alkyl resin	13	..	..
0.5 per cent rosin soap plus 0.5 per cent lime-sulfur	11	26	0.5
Sulfur dust	76	4	1.0
Dust consisting of 10 per cent cuprous oxide, 10 per cent iron oxide, and 80 per cent filler	..	55	11
Dust consisting of 50 per cent sulfur, 5 per cent basic copper sulfate, 10 per cent iron oxide, and 35 per cent filler	32	..	..

plants were treated separately with the test fungicides at intervals of three days (all being treated the first day of the test), appropriate checks were maintained, and all were exposed to conditions of heavy natural inoculation in a cool unheated greenhouse. The test was started December 27, 1940, and results were recorded January 22, 1941. The checks showed 92 per cent infection, the rosin lime-sulfur series showed 0, 2, 7, and 15 per cent infection on plants treated every 3, 6, 9, and 12 days, respectively, and the sulfur-dust series showed 59, 32, 27, and 39 per cent infection in a similar series. It is obvious that the spray was much more pronounced in its protective action than the dust.

In addition to the spray and dust trials in the experimental greenhouses, trials of sprays and dusts were made in commercial nurseries. As sources of inoculum, flats of heavily infected plants were maintained close to the test flats. Treatments were applied every 3 to 8 days, starting when the seedlings were coming through the soil or about that time. Results of three typical tests are given in table 2. In these, as in other tests of this type not reported, no treatment ever gave perfect control though with most treatments disease control was marked, and the results might be considered commercially satisfactory. Rosin lime-sulfur spray, with an average of 82 per cent control, was perhaps the best treatment; but sulfur dust at 3-day intervals was a close rival.

CONTROL BY RESISTANT VARIETIES

One seed company in southern California attempted to develop mildew-resistant snapdragons but the attempt was abandoned in favor of fungicidal control with rosin lime-sulfur. The possibility that seed produced by plants which recovered from systemic infection (fig. 1) might produce seedlings carrying factors for resistance was investigated. Seed was saved from 2 plants which had recovered by sending out healthy shoots from the systemically infected growing point. In the first trial, 27 seedlings from such seed were inoculated and all became systemically infected. This line of investigation was therefore discontinued.

SUMMARY

Snapdragon downy mildew, a relatively new disease of restricted world distribution, has been severe on nursery seedlings in the San Francisco Bay area since 1938, and in southern California since 1939. Only *Antirrhinum orontium, A. majus,* and *A. nuttallianum* are known to be affected.

In a suitable environment, symptoms may appear in as little as 4 days after inoculation. Symptoms of systemic infection consist of a down curling, paling, and rosetting of the leaves and a stunting of the plant. Local infections, which are of little importance, cause the formation of pale-green areas with diffuse margins. Recovery from systemic infection is frequently manifested by the formation of noninfected shoots from systemically infected plants. On plants about to come into flower a rosetting of the growing point occurs.

The causal organism *Peronospora antirrhini* has dichotomously branched sporangiophores and branched haustoria and produces oöspores in abundance in the cortex of systemically infected plants. Germination of the sporangia is by a germ tube. The optimum temperature for the causal organism is about 10° C. High humidity is necessary for infection.

Control by forced air circulation, by the vapor from paradichlorobenzene crystals, by sulfur dust, and by rosin lime-sulfur and other sprays has been demonstrated. The first and last of these treatments are considered most practical in localities where the disease has become established.

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